US009071297B2

(12) United States Patent
Chen et al.

(10) Patent No.: US 9,071,297 B2
(45) Date of Patent: Jun. 30, 2015

(54) **USER EQUIPMENT AND METHODS FOR CODEBOOK SUBSAMPLING FOR ENHANCED 4TX CODEBOOKS**

(71) Applicants: **Xiaogang Chen**, Beijing (CN); **Yuan Zhu**, Beijing (CN); **Qinghua Li**, San Ramon, CA (US)

(72) Inventors: **Xiaogang Chen**, Beijing (CN); **Yuan Zhu**, Beijing (CN); **Qinghua Li**, San Ramon, CA (US)

(73) Assignee: **Intel IP Corporation**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/108,648**

(22) Filed: **Dec. 17, 2013**

(65) **Prior Publication Data**

US 2014/0355705 A1 Dec. 4, 2014

Related U.S. Application Data

(60) Provisional application No. 61/829,968, filed on May 31, 2013.

(51) **Int. Cl.**
H04B 7/04 (2006.01)
H04B 7/06 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04B 7/0456*** (2013.01); ***H04B 7/0626*** (2013.01); ***H04B 7/0486*** (2013.01); ***H04B 7/0632*** (2013.01); ***H04W 12/02*** (2013.01); ***H04W 48/16*** (2013.01)

(58) **Field of Classification Search**
CPC .. H04B 7/0639; H04B 7/0626; H04B 7/0486; H04B 7/0632; H04B 7/0456; H04B 7/0621
USPC 375/259–260, 267, 295, 377; 370/229–230, 235, 310, 351, 317, 503, 370/252, 464–465
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,639,198 B2 * 1/2014 Liu et al. 455/115.1
2010/0268775 A1 10/2010 Doppler et al.
(Continued)

FOREIGN PATENT DOCUMENTS

KR 1020120031895 A 4/2012
WO WO-2007044597 A2 4/2007
(Continued)

OTHER PUBLICATIONS

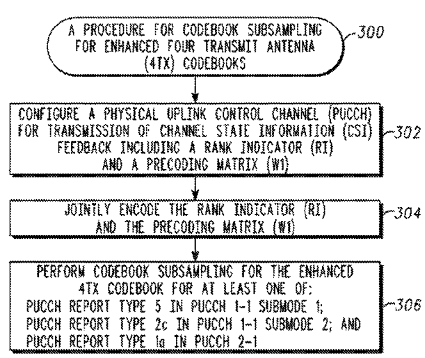
"International Application Serial No. PCT/US2014/039072, International Search Report nailed Sep. 25, 2014", 4 pgs.
(Continued)

Primary Examiner — Jean B Corrielus
(74) *Attorney, Agent, or Firm* — Schwegman Lundberg & Woessner, P.A.

(57) **ABSTRACT**

Embodiments of user equipment (UE) and methods for codebook subsampling for enhanced 4TX codebooks in 3GPP LTE wireless networks are generally described herein. In some embodiments, a physical uplink control channel (PUCCH) is configured for transmission of channel state information (CSI) feedback including a rank indicator (RI) and a precoding matrix (W1). The rank indicator (RI) and a precoding matrix (W1) are jointly encoded and codebook subsampling is performed for the enhanced 4Tx codebook for at least one of: PUCCH report type 5 (RI/1st PMI) in PUCCH 1-1 submode 1; PUCCH report type 2c (CQI/1st PMI/2nd PMI) in PUCCH 1-1 submode 2; and PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1.

10 Claims, 2 Drawing Sheets



(51) **Int. Cl.**

H04W 12/02	(2009.01)
H04W 48/16	(2009.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2012/0087425	A1	4/2012	Gomadam et al.	
2012/0093098	A1	4/2012	Charbit et al.	
2012/0218948	A1	8/2012	Onggosanusi et al.	
2012/0219042	A1	8/2012	Onggosanusi et al.	
2012/0220286	A1	8/2012	Chen et al.	
2013/0040677	A1	2/2013	Lee et al.	
2013/0077704	A1*	3/2013	Ding et al.	375/267
2014/0086352	A1*	3/2014	Ko et al.	375/267
2014/0169300	A1*	6/2014	Kim et al.	370/329
2014/0219219	A1*	8/2014	Onggosanusi et al.	370/329
2014/0254701	A1*	9/2014	Geirhofer et al.	375/267
2014/0286452	A1*	9/2014	Gomadam et al.	375/267
2014/0357228	A1	12/2014	Luft et al.	

FOREIGN PATENT DOCUMENTS

WO	WO-2014193718	A1	12/2014
WO	WO-2014193749	A1	12/2014

OTHER PUBLICATIONS

"International Application Serial No. PCT/US2014/039072, Written Opinion mailed Sep. 25, 2014", 5 pgs.

"International Application Serial No. PCT/US2014/039313, International Search Report mailed Sep. 26, 2014", 4 pgs.

"International Application Serial No. PCT/US2014/039313, Written Opinion mailed Sep. 26, 2014", 5 pgs.

* cited by examiner

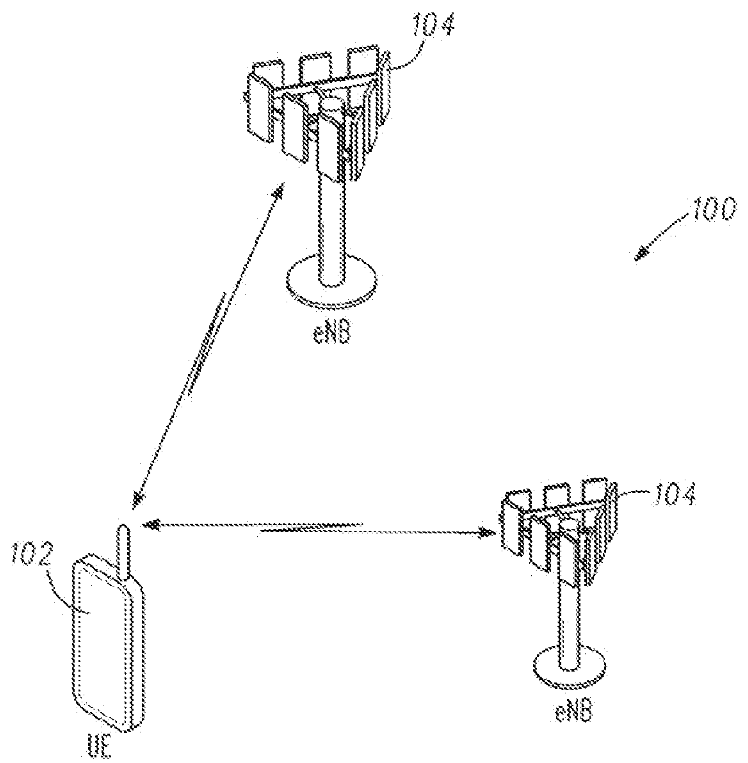

104
100
eNB
104
102
eNB
UE

Fig. 1

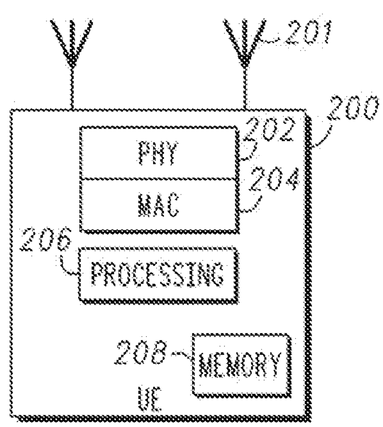

201
200
PHY
202
MAC
204
206
PROCESSING
208
MEMORY
UE

Fig. 2

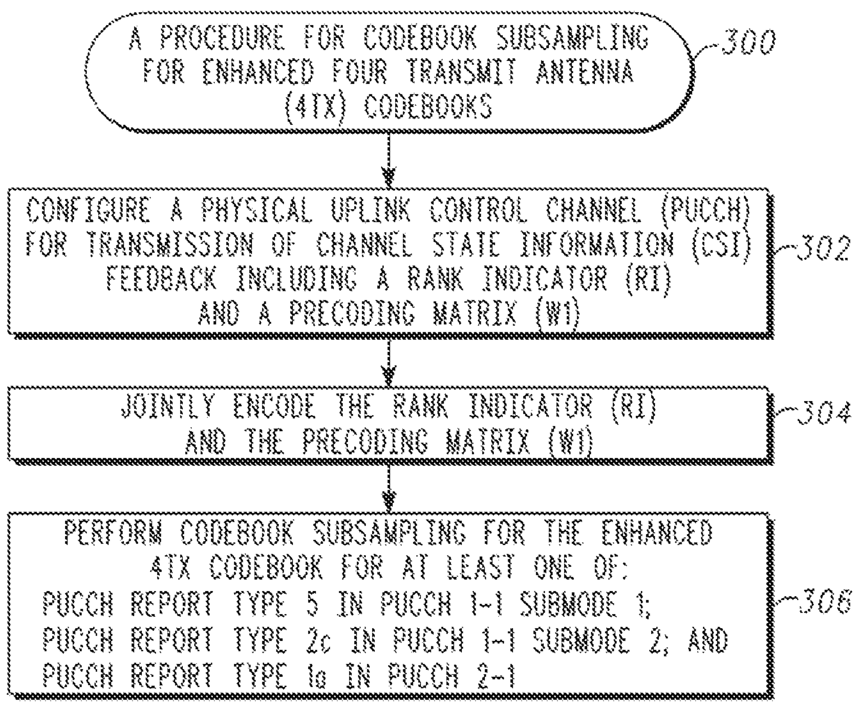

A PROCEDURE FOR CODEBOOK SUBSAMPLING FOR ENHANCED FOUR TRANSMIT ANTENNA (4TX) CODEBOOKS
300
CONFIGURE A PHYSICAL UPLINK CONTROL CHANNEL (PUCCH) FOR TRANSMISSION OF CHANNEL STATE INFORMATION (CSI) FEEDBACK INCLUDING A RANK INDICATOR (RI) AND A PRECODING MATRIX (W1)
302
JOINTLY ENCODE THE RANK INDICATOR (RI) AND THE PRECODING MATRIX (W1)
304
PERFORM CODEBOOK SUBSAMPLING FOR THE ENHANCED 4TX CODEBOOK FOR AT LEAST ONE OF:
PUCCH REPORT TYPE 5 IN PUCCH 1-1 SUBMODE 1;
PUCCH REPORT TYPE 2c IN PUCCH 1-1 SUBMODE 2; AND
PUCCH REPORT TYPE 1a IN PUCCH 2-1
306

Fig. 3

USER EQUIPMENT AND METHODS FOR CODEBOOK SUBSAMPLING FOR ENHANCED 4TX CODEBOOKS

PRIORITY CLAIM

This application claims priority under 35 USC 119(e) to U.S. Provisional Patent Application Ser. No. 61/829,968, filed May 31, 2013, [reference number P56512Z] which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

Embodiments pertain to wireless communications. Some embodiments relate to multiple-input multiple output (MIMO) codebook subsampling in cellular networks, such as E-UTRAN networks operating in accordance with one of the 3GPP standards for the Long Term Evolution (LTE) (3GPP LTE).

BACKGROUND

Closed-loop MIMO systems typically transmit channel state information from a receiver to a transmitter over a feedback path. The channel state information may be used to employ beamforming to compensate for the current channel conditions increasing signal-to-noise (SNR) levels at the receiver. In some of these conventional systems, a beamforming matrix may be generated at the receiver based on the channel conditions. The beamforming matrix may then be provided to the transmitter as feedback. This feedback consumes bandwidth that might otherwise be available for data traffic. To reduce the overhead associated with this feedback, codewords of a known codebook may be provided instead of an actual beamforming matrix. The codewords may indicate which beamforming matrix is to be used by the transmitter.

In MIMO systems, the size of the codebooks may increase significantly with number of transmit antennas N_t and the number of transmitted data streams N_s. In some conventional systems, the size of the codebook may be based on the number of transmit antennas and the number of data streams. This results in a significant increase in feedback.

Thus, there are general needs for MIMO systems and methods for beamforming with reduced feedback. There are also general needs for MIMO systems and methods that make use of smaller codebooks. There are also general needs for MIMO systems and methods that provide improved performance without an increase in feedback.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a wireless network in accordance with some embodiments; and

FIG. **2** illustrates a functional block diagram of user equipment (UE) in accordance with some embodiments.

FIG. **3** is a procedure for codebook subsampling for enhanced four transmit antenna (4TX) codebooks in accordance with some embodiments.

DETAILED DESCRIPTION

The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

FIG. **1** illustrates a wireless network in accordance with some embodiments. Wireless network may be configured to operate in accordance with one of the 3GPP standards for the Long Term Evolution (LTE) (3GPP LTE). In these embodiments, wireless network **100** may include one or more enhanced node Bs (eNBs) **104** arranged for communicating with user equipment (UE), such as UE **102**. UE **102** may provide feedback **103** to an eNB **104** for performing MIMO beamforming, among other things, as described in more detail below.

In accordance with some embodiments, the UE **102** may be arranged for codebook subsampling for enhanced 4TX codebooks in a 3GPP LTE network. IN these embodiments, the UE **102** may configure a physical uplink control channel (PUCCH) for transmission of channel state information (CSI) feedback including a rank indicator (RI) and a precoding matrix (W1), may jointly encode a rank indicator (RI) and a precoding matrix (W1), and may perform codebook subsampling for the enhanced 4Tx codebook for: PUCCH report type 5 (RI/1st PMI) in PUCCH 1-1 submode 1; PUCCH report type 2c (CQI/1st PMI/2nd PMI) in PUCCH 1-1 submode 2; and PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1. These embodiments are described in more detail below.

In some embodiments, for the PUCCH report type 5 (RI/1st PMI) in PUCCH 1-1 submode 1, when a maximum of four layers of data transmission (i.e., RI=1, 2, 3, or 4) is supported by the UE **102**, the UE **102** may jointly encode the RI and the W1 by employing codebook subsampling prior to configuring the CSI transmission (e.g., see table 2-1) at least for a rank indicator of two (RI=2).

In some embodiments, precoding matrix indices of 2, 4, 6, 8, 10, 12 and 14 are used for the codebook subsampling for RI=2 when a maximum of four layers of data transmission is supported (e.g., see table 2-1) to limit the PUCCH payload size for RI feedback to 5-bits.

In some embodiments, precoding matrix indices of 0-7 are used for the codebook subsampling for RI=2 when a maximum of four layers of data transmission is supported to limit the PUCCH payload size for RI feedback to 5-bits. (e.g., see table 2-2).

In some embodiments, precoding matrix indices of 0-6 and 8-14 are used for the codebook subsampling for RI=2 when a maximum of four layers of data transmission is supported to limit the PUCCH payload size for RI feedback to 5-bits. (e.g., see table 3-1).

In some embodiments, precoding matrix indices of 0-13 are used for the codebook subsampling for RI=2 when a maximum of four layers of data transmission is supported (e.g., see table 3-1) to limit the PUCCH payload size for RI feedback to 5-bits.

In some embodiments, when a maximum of two layers of data transmission (i.e., RI=1 or 2) is supported, the RI and W1 are jointly encoded. In these embodiments, the UE **102** may refrain from performing codebook sampling (see table 1).

In some embodiments, the UE **102** may configure PUCCH payload to be 11-bits for the CSI feedback when the CSI feedback includes a channel-quality indicator (CQI) and a precoding matrix indicator (PMI). The UE **102** may configure the PUCCH payload to be 5-bits for the CSI feedback when the CSI feedback includes the RI. In these embodiments, as long as the RI is included (even without PMI), the payload should be less or equal to 5 bits.

In some embodiments, for PUCCH report type 2c (CQI/1st PMI/2nd PMI) in PUCCH 1-1 submode 2, the method comprises performing codebook subsampling for RI=1 or RI=2 in accordance with either table 4-1 or table 4-2.

In some embodiments, for PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1, the method comprises performing codebook subsampling for RI=1, RI=2, RI=3 or RI=4 in accordance with table 5, table 6 or table 7.

In some embodiments, a dual codebook structure may be used for enhanced 4Tx codebook. Two solutions are proposed for down selection as follows:

Solution 2a

$$W_1 = \begin{bmatrix} X_n & 0 \\ 0 & X_n \end{bmatrix}$$

where $n = 0, 1, \ldots, 15$

$$X_n = \begin{bmatrix} 1 & 1 & 1 & 1 \\ q_1^n & q_1^{n+8} & q_1^{n+16} & q_1^{n+24} \end{bmatrix}$$

where $q_1 = e^{j2\pi/32}$

For rank 1,

$$W_{2,n} \in \left\{ \frac{1}{\sqrt{2}} \begin{bmatrix} Y \\ \alpha(i)Y \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} Y \\ j\alpha(i)Y \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} Y \\ -\alpha(i)Y \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} Y \\ -j\alpha(i)Y \end{bmatrix} \right\}$$

and $Y \in \{e_1, e_2, e_3, e_4\}$ and $\alpha(i) = q_1^{2(i-1)}$;

For rank 2, $W_{2,n} \in \left\{ \frac{1}{2} \begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2} \begin{bmatrix} Y_1 & Y_2 \\ jY_1 & -jY_2 \end{bmatrix} \right\}$

and $(Y_1, Y_2) = (e_i, e_k) \in \{(e_1, e_1), (e_2, e_2), (e_3, e_3), (e_4, e_4), (e_1, e_2), (e_2, e_3), (e_1, e_4), (e_2, e_4)\}$;

Solution 2b

$$W_1 = \begin{bmatrix} X_n & 0 \\ 0 & X_n \end{bmatrix}$$

where $n = 0, 1, \ldots, 15$

$$X_n = \begin{bmatrix} 1 & 1 & 1 & 1 \\ q_1^n & q_1^{n+8} & q_1^{n+16} & q_1^{n+24} \end{bmatrix}$$

where $q_1 = e^{j2\pi/32}$

For rank 1,

$$W_{2,n} \in \left\{ \frac{1}{\sqrt{2}} \begin{bmatrix} Y \\ \alpha(i)Y \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} Y \\ j\alpha(i)Y \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} Y \\ -\alpha(i)Y \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} Y \\ -j\alpha(i)Y \end{bmatrix} \right\}$$

and $Y \in \{e_1, e_2, e_3, e_4\}$ and $\alpha(i) = q_1^{2(i-1)}$;

For rank 2,

$$W_{2,n} \in \left\{ \frac{1}{2} \begin{bmatrix} Y_1 & Y_2 \\ Y_1 & Y_2 \end{bmatrix}, \frac{1}{2} \begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2} \begin{bmatrix} Y_1 & Y_2 \\ -Y_1 & Y_2 \end{bmatrix}, \frac{1}{2} \begin{bmatrix} Y_1 & Y_2 \\ -Y_1 & -Y_2 \end{bmatrix} \right\} (Y_1, Y_2) \in \{(e_2, e_4)\}$$

and

$$W_{2,n} \in \left\{ \frac{1}{2} \begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2} \begin{bmatrix} Y_1 & Y_2 \\ jY_1 & -jY_2 \end{bmatrix} \right\} (Y_1, Y_2) \in \{(e_1, e_1), (e_2, e_2), (e_3, e_3), (e_4, e_4)\}$$

and

$$W_{2,n} \in \left\{ \frac{1}{2} \begin{bmatrix} Y_1 & Y_2 \\ Y_2 & -Y_1 \end{bmatrix}, \right\} (Y_1, Y_2) \in \{(e_1, e_3), (e_2, e_4), (e_3, e_1), (e_4, e_2)\}$$

Similar with 8Tx dual codebook, codebook subsampling should be applied for periodic CSI feedback to meet the PUCCH feedback channel capacity. This disclosure proposes the codebook subsampling schemes for enhanced 4Tx codebook in periodic CSI feedback.

In accordance with embodiments, in order to achieve reliable CSI feedback, the PUCCH payload should be no more than:

11 bits if current CSI feedback instance includes CQI/PMI feedback;

5 bits if current CSI feedback instance includes RI feedback.

Then codebook subsampling may be applied for: PUCCH report type 5 (RI/1st PMI) in PUCCH 1-1 submode 1; PUCCH report type 2c (CQI/1st PMI/2nd PMI) in PUCCH 1-1 submode 2; PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1; for the enhanced 4Tx codebook.

Codebook Subsample for PUCCH 1-1 Submode 1:

Since the enhanced 4Tx codebook reuse Re1.8 codebook for rank 3~4 and W1 is an identity matrix, subsampling of W1 (1st PMI) only needs to take rank 1~2 into consideration. In order to limit the payload size of PUCCH report type 5 within 5 bits, the following scheme could be used:

Alt 1): If the UE supports maximum 2 layer transmission, no subsampling is needed. RI and W1 could be jointly encoded following table 1.

TABLE 1

RI	W1 index after sub-sampling	No. W1 hypotheses
1	0 ~ 15	16
2	0 ~ 15	16
Total no. W1 + RI hypotheses across ranks 1-2 (max. layers = 2)		32 (5 bits)

If the UE supported maximum layer is 4, RI and W1 could be jointly encoded following table 2-1 or table 2-2.

The principle for rank 1 is to keep as many W1 as possible. For rank 2, table 2-1 is optimized to equally subsample W1 of rank 2 for solution 2a; table 2-2 is optimized for solution 2b to avoid duplicated codewords.

Note that table 2-1 and table 2-2 could also be used as a unified solution even if UE supports maximum 2 layer transmission.

TABLE 2-1

RI	W1 index after sub-sampling	No. W1 hypotheses
1	0 ~ 15	16
2	0, 2, 4, 6, 8, 10, 12, 14	8
3	0	1
4	0	1
Total no. W1 + RI hypotheses across ranks 1-4 (max. layers = 4)		26 (5 bits)

TABLE 2-2

RI	WI index after sub-sampling	No. W1 hypotheses
1	0 ~ 15	16
2	0 ~ 7	8
3	0	1
4	0	1
Total no. W1 + RI hypotheses across ranks 1-4 (max. layers = 4)		26 (5 bits)

Alt 2): Another alternative is the same as alt 1) except table 2-1 and table 2-2 are changed to table 3-1 and table 3-2

respectively to effectively use the 32 W1 hypotheses that could be indicated with 5 bits.

TABLE 3-1

RI	W1 index after sub-sampling	No. W1 hypotheses
1	0 ~ 15	16
2	0 ~ 6, 8 ~ 14	14
3	0	1
4	0	1
Total no. W1 + RI hypotheses across ranks 1-4 (max. layers = 4)		32 (5 bits)

TABLE 3-2

RI	WI index after sub-sampling	No. W1 hypotheses
1	0 ~ 15	16
2	0 ~ 13	14
3	0	1
4	0	1
Total no. W1 + RI hypotheses across ranks 1-4 (max. layers = 4)		32 (5 bits)

Codebook Subsample for PUCCH 1-1 Submode 2:

Since the enhanced 4Tx codebook of rank 3~4 reuse Rel.8 codebook and W1 is an identity matrix, W2 could be indicated by 4 bits for rank 3~4. Then no subsampling is needed for PUCCH 1-1 submode 2 in rank 3~4.

For rank 1~2, the table 4-1 or table 4-2 could be used for codebook subsampling. The principle of subsampling for rank 1 is to equally distribute the DFT precoding vector within the AoD (angle of departure) range of eNB. The principle of subsampling for rank 2 is to keep all of the 2 possible co-phasing while covering eNB's AoD range with W1 as much as possible.

The definition of e_i is the same, i.e. e_i is a 4×1 vector with the ith component equals to 1 and the other components are zero. e.g. e1=[1 0 0 0]';

TABLE 4-1

RI	W1 + W2 index after sub-sampling	No. W1 + W2 hypotheses
1	W1: 0, 2, 4, 6, 8, 10, 12, 14 or 1, 3, 5, 7, 9, 11, 13, 15 W2: 0~15	128 (7 bits)
2	W1: 0, 2, 4, 6, 8, 10, 12, 14 or 1, 3, 5, 7, 9, 11, 13, 15 W2: for each W1, choose only (Y1, Y2) = (e1, e1) with all 2 possible co-phasing, i.e. $W_{2,n} \in \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ jY_1 & -jY_2 \end{bmatrix}\right\}$, with (Y1, Y2) = (e1, e1)	8 × 2 = 16 (4 bits)

TABLE 4-2

RI	W1 + W2 index after sub-sampling	No. W1 + W2 hypotheses
1	W1: 0, 2, 4, 6, 8, 10, 12, 14 or 1, 3, 5, 7, 9, 11, 13, 15 W2: 0~15	128 (7 bits)
2	W1: 0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 W2: for each W1, choose (Y1, Y2) = (e1, e1) with all 2 possible co-phasing, i.e. $W_{2,n} \in \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ jY_1 & -jY_2 \end{bmatrix}\right\}$, with (Y1, Y2) = (e1, e1); and choose (Y1, Y2) = (e2, e4) with $W_{2,n} = \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & Y_2 \end{bmatrix}\right\}$; and chose (Y1, Y2) = (e1, e3) with $W_{2,n} \in \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_2 & -Y_1 \end{bmatrix}\right\}$	4 × (2 + 1 + 1) = 16 (4 bits)

Codebook Subsample for PUCCH 2-1:

Regarding PUCCH reporting type 1a, i.e. subband CQI/second PMI reporting, the codebook subsampling of table 5 or table 6 or table 7 could be applied.

TABLE 5

RI	W2 index after sub-sampling	No. W2 hypotheses
1	0~15	16 (4 bits)
2	W2: for each W1, choose (Y1, Y2)∈{(e1, e1), (e2, e2)} with all 2 possible co-phasing, i.e. $W_{2,n} \in \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ jY_1 & -jY_2 \end{bmatrix}\right\}$, with (Y1, Y2)∈ {(e1, e1), (e3, e3)}	2 × 2 = 4 (2 bits)
3	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)
4	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)

TABLE 6

RI	W2 index after sub-sampling	No. W2 hypotheses
1	0~15	16 (4 bits)
2	W2: for each W1, choose (Y1, Y2)∈ {(e1, e1), (e2, e2), (e3, e3), (e4, e4)} with only 1 co-phasing, i.e. $W_{2,n} \in \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}\right\}$ with (Y1, Y2)∈ {(e1, e1), (e2, e2), (e3, e3), (e4, e4)}	4 × 1 = 4 (2 bits)
3	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)
4	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)

TABLE 7

RI	W2 index after sub-sampling	No. W2 hypotheses
1	0~15	16 (4 bits)
2	W2: for each W1, choose (Y1, Y2) = (e1, e1) with all 2 possible co-phasing, i.e.	2 + 1 + 1 = 4 (2 bits)

TABLE 7-continued

RI	W2 index after sub-sampling	No. W2 hypotheses
	$W_{2,n} \in \left\{ \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ jY_1 & -jY_2 \end{bmatrix} \right\}$, with (Y1, Y2) = (e1, e1); and choose (Y1, Y2) = (e2, e4) with $W_{2,n} = \left\{ \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & Y_2 \end{bmatrix} \right\}$; and choose (Y1, Y2) = (e1, e3) with $W_{2,n} \in \left\{ \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_2 & -Y_1 \end{bmatrix} \right\}$	
3	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)
4	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)

FIG. **2** illustrates a functional block diagram of a UE in accordance with some embodiments. UE **200** may be suitable for use as UE **102** (FIG. **1**). The UE **200** may include physical layer circuitry **202** for transmitting and receiving signals to and from eNBs **104** (FIG. **1**) using one or more antennas **201**. UE **200** may also include medium access control layer (MAC) circuitry **204** for controlling access to the wireless medium. UE **200** may also include processing circuitry **206** and memory **208** arranged to perform the operations described herein.

In some embodiments, the UE **200** may be part of a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the UE **200** may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

The one or more antennas **201** utilized by the UE **200** may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some embodiments, instead of two or more antennas, a single antenna with multiple apertures may be used. In some multiple-input multiple-output (MIMO) embodiments, the antennas may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result between each of antennas and the antennas of a transmitting station. In some MIMO embodiments, the antennas may be separated by up to 1/10 of a wavelength or more.

Although the UE **200** is illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements.

Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage medium, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage medium may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage medium may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. In these embodiments, one or more processors may be configured with the instructions to perform the operations described herein.

In some embodiments, the UE **200** may be configured to receive OFDM communication signals over a multicarrier communication channel in accordance with an OFDMA communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers. In some broadband multicarrier embodiments, eNBs (including macro eNB **104** and pico eNBs) may be part of a broadband wireless access (BWA) network communication network, such as a Worldwide Interoperability for Microwave Access (WiMAX) communication network or a 3rd Generation Partnership Project (3GPP) Universal Terrestrial Radio Access Network (UTRAN) Long-Term-Evolution (LTE) or a Long-Term-Evolution (LTE) communication network, although the scope of the invention is not limited in this respect. In these broadband multicarrier embodiments, the UE **200** and the eNBs may be configured to communicate in accordance with an orthogonal frequency division multiple access (OFDMA) technique.

In some LTE embodiments, the basic unit of the wireless resource is the Physical Resource Block (PRB). The PRB may comprise 12 sub-carriers in the frequency domain×0.5 ms in the time domain. The PRBs may be allocated in pairs (in the time domain) In these embodiments, the PRB may comprise a plurality of resource elements (REs). A RE may comprise one sub-carrier×one symbol.

Two types of reference signals may be transmitted by an eNB including demodulation reference signals (DM-RS), channel state information reference signals (CIS-RS) and/or a common reference signal (CRS). The DM-RS may be used by the UE for data demodulation. The reference signals may be transmitted in predetermined PRBs.

In some embodiments, the OFDMA technique may be either a frequency domain duplexing (FDD) technique that uses different uplink and downlink spectrum or a time-domain duplexing (TDD) technique that uses the same spectrum for uplink and downlink.

In some other embodiments, the UE **200** and the eNBs may be configured to communicate signals that were transmitted using one or more other modulation techniques such as spread spectrum modulation (e.g., direct sequence code division multiple access (DS-CDMA) and/or frequency hopping code division multiple access (FH-CDMA)), time-division multiplexing (TDM) modulation, and/or frequency-division multiplexing (FDM) modulation, although the scope of the embodiments is not limited in this respect.

In some LTE embodiments, the UE **200** may calculate several different feedback values which may be used to perform channel adaption for closed-loop spatial multiplexing transmission mode. These feedback values may include a channel-quality indicator (CQI), a rank indicator (RI) and a precoding matrix indicator (PMI). By the CQI, the transmitter selects one of several modulation alphabets and code rate combinations. The RI informs the transmitter about the number of useful transmission layers for the current MIMO channel, and the PMI indicates the codebook index of the precoding matrix (depending on the number of transmit antennas) that is applied at the transmitter. The code rate used by the eNB may be based on the CQI. The PMI may be a vector that is calculated by the UE and reported to the eNB. In some embodiments, the UE may transmit a physical uplink control channel (PUCCH) of format 2, 2a or 2b containing the CQI/PMI or RI.

In these embodiments, the CQI may be an indication of the downlink mobile radio channel quality as experienced by the UE **200**. The CQI allows the UE **200** to propose to an eNB an optimum modulation scheme and coding rate to use for a given radio link quality so that the resulting transport block error rate would not exceed a certain value, such as 10%. In some embodiments, the UE may report a wideband CQI value which refers to the channel quality of the system bandwidth. The UE may also report a sub-band CQI value per sub-band of a certain number of resource blocks which may be configured by higher layers. The full set of sub-bands may cover the system bandwidth. In case of spatial multiplexing, a CQI per code word may be reported.

In some embodiments, the PMI may indicate an optimum precoding matrix to be used by the eNB for a given radio condition. The PMI value refers to the codebook table. The network configures the number of resource blocks that are represented by a PMI report. In some embodiments, to cover the system bandwidth, multiple PMI reports may be provided. PMI reports may also be provided for closed loop spatial multiplexing, multi-user MIMO and closed-loop rank 1 precoding MIMO modes.

In some cooperating multipoint (CoMP) embodiments, the network may be configured for joint transmissions to a UE in which two or more cooperating/coordinating points, such as remote-radio heads (RRHs) transmit jointly. In these embodiments, the joint transmissions may be MIMO transmissions and the cooperating points are configured to perform joint beamforming.

FIG. **3** is a procedure **300** for codebook subsampling for enhanced four transmit antenna (4TX) codebooks in a Third-Generation Partnership (3GPP) Project Long Term Evolution (LTE) network. Procedure **300** may be performed by user equipment (UE), such as UE **200** (FIG. **2**).

Operation **302** comprises configuring a physical uplink control channel (PUCCH) for transmission of channel state information (CSI) feedback including a rank indicator (RI) and a precoding matrix (W1). Operation **304** comprises jointly encoding the rank indicator (RI) and the precoding matrix (W1). Operation **306** comprises performing codebook subsampling for the enhanced 4TX codebook for at least one of: PUCCH report type 5 (RI/1st precoding matrix indicator (PMI)) in PUCCH 1-1 submode 1: PUCCH report type 2c (channel quality indicator (CQI)/1st PMI/2nd PMI) in PUCCH 1-1 submode 2, and PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1.

The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

What is claimed is:

1. A method for codebook subsampling for enhanced four transmit antenna (4TX) codebooks in a Third-Generation Partnership (3GPP) Project Long Term Evolution (LTE) network performed by user equipment (UE), the method comprising:

configuring a physical uplink control channel (PUCCH) for transmission of channel state information (CSI) feedback including a rank indicator (RI) and a precoding matrix (W1);

jointly encoding the rank indicator (RI) and the precoding matrix (W1); and

performing codebook subsampling for the enhanced 4TX codebook for at least one of:

PUCCH report type 5 (RI/1st precoding matrix indicator (PMI)) in PUCCH 1-1 submode 1;

PUCCH report type 2c (channel quality indicator (CQI)/1st PMI/2nd PMI) in PUCCH 1-1 submode 2; and

PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1,

wherein the UE is configurable to perform codebook subsampling for the enhanced 4TX codebook for the PUCCH report type 5, the PUCCH report type 2c, and the PUCCH report type 1a and

wherein for the PUCCH report type 5 (RI/1st PMI) in PUCCH 1-1 submode 1, when a maximum of four layers of data transmission is supported by the UE, the method includes, jointly encoding the RI and the W1 by employing codebook subsampling prior to configuring the CSI transmission at least for a rank indicator of two.

2. The method of claim **1**, wherein precoding matrix indices of 2, 4, 6, 8, 10, 12 and 14 are used for the codebook subsampling for RI=2 when a maximum of four layers of data transmission is supported to limit the PUCCH payload size for RI feedback to 5-bits.

3. The method of claim **1**, wherein precoding matrix indices of 0-7 are used for the codebook subsampling for RI=2 when a maximum of four layers of data transmission is supported to limit the PUCCH payload size for RI feedback to 5-bits.

4. The method of claim **1**, wherein precoding matrix indices of 0-6 and 8-14 are used for the codebook subsampling for RI=2 when a maximum of four layers of data transmission is supported to limit the PUCCH payload size for RI feedback to 5-bits.

5. The method of claim **1**, wherein precoding matrix indices of 0-13 are used for the codebook subsampling for RI=2 when a maximum of four layers of data transmission is supported to limit the PUCCH payload size for RI feedback to 5-bits.

6. The method of claim **1** further comprising:

configuring a PUCCH payload to be 11-bits for the CSI feedback when the CSI feedback includes a channel-quality indicator (CQI) and a precoding matrix indicator (PMI); and

configuring a PUCCH payload to be 5-bits for the CSI feedback when the CSI feedback includes the RI.

7. A method for codebook sub sampling for enhanced four transmit antenna (4TX) codebooks in a Third-Generation Partnership (3GPP) Project Long Term Evolution (LTE) network performed by user equipment (UE), the method comprising:

configuring a physical uplink control channel (PUCCH) for transmission of channel state information (CSI) feedback including a rank indicator (RI) and a precoding matrix (W1);

jointly encoding the rank indicator (RI) and the precoding matrix (W1); and

performing codebook subsampling for the enhanced 4TX codebook for at least one of:

PUCCH report type 5 (RI/1st precoding matrix indicator (PMI)) in PUCCH 1-1 submode 1;

PUCCH report type 2c (channel quality indicator (CQI)/1st PMI/2nd PMI) in PUCCH 1-1 submode 2; and

PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1,

wherein the UE is configurable to perform codebook subsampling for the enhanced 4TX codebook for the PUCCH report type 5, the PUCCH report type 2c, and the PUCCH report type 1a and

wherein for PUCCH report type 2c (CQI/1st PMI/2nd PMI) in PUCCH 1-1 submode 2, the method comprises performing codebook subsampling for RI=1 or RI=2 in accordance with either table 4-1 or table 4-2:

TABLE 4-1

RI	W1 + W2 index after sub-sampling	No. W1 + W2 hypotheses
1	W1: 0, 2, 4, 6, 8, 10, 12, 14 or 1, 3, 5, 7, 9, 11, 13, 15 W2: 0~15	128 (7 bits)
2	W1: 0, 4, 6, 8, 10, 12, 14 or 1, 3, 5, 7, 9, 11, 13, 15 W2: for each W1, choose only (Y1, Y2) = (e1, e1) with all 2 possible co-phasing, i.e. $W_{2,n} \in \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ jY_1 & -jY_2 \end{bmatrix}\right\}$, with (Y1, Y2) = (e1, e1)	8 × 2 = 16 (4 bits)

TABLE 4-2

RI	W1 + W2 index after sub-sampling	No. W1 + W2 hypotheses
1	W1: 0, 2, 4, 6, 8, 10, 12, 14 or 1, 3, 5, 7, 9, 11, 13, 15 W2: 0~15	128 (7 bits)
2	W1: 0, 4, 8, 10, 12 or 2, 6, 10, 14 or 3, 7, 11, 15 W2: for each W1, choose (Y1, Y2) = (e1, e1) with all 2 possible co-phasing, i.e. $W_{2,n} \in \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ jY_1 & -jY_2 \end{bmatrix}\right\}$, with (Y1, Y2) = (e1, e1); and choose (Y1, Y2) = (e2, e4) with $W_{2,n} = \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & Y_2 \end{bmatrix}\right\}$; and chose (Y1, Y2) = (e1, e3) with $W_{2,n} \in \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_2 & -Y_1 \end{bmatrix}\right\}$	4 × (2 + 1 + 1) = 16 (4 bits)

8. A method for codebook subsampling for enhanced four transmit antenna (4TX) codebooks in a Third-Generation Partnership (3GPP) Project Long Term Evolution (LTE) network performed by user equipment (UE), the method comprising:

configuring a physical uplink control channel (PUCCH) for transmission of channel state information (CSI) feedback including a rank indicator (RI) and a precoding matrix (W1);

jointly encoding the rank indicator (RI) and the precoding matrix (W1); and

performing codebook subsampling for the enhanced 4TX codebook for at least one of:

PUCCH report type 5 (RI/1st precoding matrix indicator (PMI)) in PUCCH 1-1 submode 1;

PUCCH report type 2c (channel quality indicator (CQI)/1st PMI/2nd PMI) in PUCCH 1-1 submode 2; and

PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1,

wherein the UE is configurable to perform codebook subsampling for the enhanced 4TX codebook for the PUCCH report type 5, the PUCCH report type 2c, and the PUCCH report type 1a and

wherein for PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1, the method comprises performing codebook subsampling for RI=1, RI=2, RI=3 or RI=4 in accordance with one of Table A, Table B or Table C:

TABLE A

I	W2 index after sub-sampling	No. W2 hypotheses
	0~15	16 (4 bits)
	W2: for each W1, choose (Y1, Y2)∈ {(e1, e1), (e2, e2)} wherein: $W_{2,n} \in \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ jY_1 & -jY_2 \end{bmatrix}\right\}$, with (Y1, Y2)∈ {(el, e1), (e3, e3)}	2 × 2 = 4 (2 bits)
	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)
	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)

TABLE B

I	W2 index after sub-sampling	No. W2 hypotheses
	0~15	16 (4 bits)
	W2: for each W1, choose (Y1, Y2)∈ {(e1, e1), (e2, e2), (e3, e3), (e4,e4) } wherein: $W_{2,n} \in \left\{\frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}\right\}$ with (Y1, Y2)∈ { (e1, e1), (e2, e2), (e3, e3), (e4, e4) }	4 × 1 = 4 (2 bits)
	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)
	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)

TABLE C

I	W2 index after sub-sampling	No. W2 hypotheses
	0~15	16 (4 bits)
	W2: for each W1, choose (Y1, Y2) = (e1, e1) wherein:	2 + 1 = 42 (2 bits)

TABLE C-continued

I	W2 index after sub-sampling	No. W2 hypotheses
	$W_{2,n} \in \left\{ \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & -Y_2 \end{bmatrix}, \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ jY_1 & -jY_2 \end{bmatrix} \right\}$, with (Y1, Y2) = (e1, e1); and choose (Y1, Y2) = (e2, e4) with $W_{2,n} = \left\{ \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_1 & Y_2 \end{bmatrix} \right\}$; and chose (Y1, Y2) = (e1, e3) with $W_{2,n} \in \left\{ \frac{1}{2}\begin{bmatrix} Y_1 & Y_2 \\ Y_2 & -Y_1 \end{bmatrix} \right\}$	
	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3	4 (2 bits)
	0, 4, 8, 12 or 1, 5, 9, 13 or 2, 6, 10, 14 or 3, 7, 11, 15 or 0, 1, 2, 3.	4 (2 bits)

9. User Equipment (UE) having processing circuitry arranged to perform codebook subsampling for enhanced four transmit antenna (4TX) codebooks when operating in a Third-Generation Partnership (3GPP) Project Long Term Evolution (LTE) network, the processing circuitry arranged to:

configure a physical uplink control channel (PUCCH) for transmission of channel state information (CSI) feedback including a rank indicator (RI) and a precoding matrix (W1);

jointly encode the rank indicator (RI) and the precoding matrix (W1); and

perform codebook subsampling for the enhanced 4TX codebook for at least one of:

PUCCH report type 5 (RI/1st precoding matrix indicator (PMI)) in PUCCH 1-1 submode 1;

PUCCH report type 2c (channel quality indicator (CQI)/1st PMI/2nd PMI) in PUCCH 1-1 submode 2; and

PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1,

wherein the UE is configurable to perform codebook subsampling for the enhanced 4TX codebook for the PUCCH report type 5, the PUCCH report type 2c, and the PUCCH report type 1a and

wherein for the PUCCH report type 5 (RI/1st PMI) in PUCCH 1-1 submode 1, when a maximum of four layers of data transmission is supported by the UE, the processing circuitry is configured to jointly encode the RI and the W1 by employing codebook subsampling prior to configuring the CSI transmission at least for a rank indicator of two.

10. A non-transitory computer-readable storage medium that stores instructions for execution by one or more processors to perform operations for codebook sub sampling for enhanced four transmit antenna (4TX) codebooks when operating in a Third-Generation Partnership (3GPP) Project Long Term Evolution (LTE) network, the operations to configure user equipment (UE) to:

configure a physical uplink control channel (PUCCH) for transmission of channel state information (CSI) feedback including a rank indicator (RI) and a precoding matrix (W1);

jointly encode the rank indicator (RI) and the precoding matrix (W1); and

perform codebook subsampling for the enhanced 4TX codebook for at least one of:

PUCCH report type 5 (RI/1st precoding matrix indicator (PMI)) in PUCCH 1-1 submode 1;

PUCCH report type 2c (channel quality indicator (CQI)/1st PMI/2nd PMI) in PUCCH 1-1 submode 2; and

PUCCH report type 1a (subband CQI/2nd PMI) in PUCCH 2-1,

wherein the UE is configurable to perform codebook subsampling for the enhanced 4TX codebook for the PUCCH report type 5, the PUCCH report type 2c, and the PUCCH report type 1a and

wherein for the PUCCH report type 5 (RI/1st PMI) in PUCCH 1-1 submode 1, when a maximum of four layers of data transmission is supported by the UE, the operations further configure the UE to jointly encode the RI and the W1 by employing codebook subsampling prior to configuring the CSI transmission at least for a rank indicator of two.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,071,297 B2
APPLICATION NO. : 14/108648
DATED : June 30, 2015
INVENTOR(S) : Chen et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title Page, Item (57), in "Abstract", in column 2, line 9, delete "4Tx" and insert --4TX--, therefor

In the Claims

In column 10, line 29, in Claim 1, delete "1a and" and insert --1a, and--, therefor

In column 11, line 17, in Claim 7, delete "1a and" and insert --1a, and--, therefor

In column 12, line 19, in Claim 8, delete "1a and" and insert --1a, and--, therefor

In column 14, line 2, in Claim 9, delete "1a and" and insert --1a, and--, therefor

In column 14, line 35, in Claim 10, delete "1a and" and insert --1a, and--, therefor

Signed and Sealed this
Sixteenth Day of February, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office